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Abstract: Prior studies investigated why older adults, even in the absence of hearing impairment, typically experience increased difficulties understanding speech in noise. ("Speech understanding and aging. Working Group on Speech Understanding and Aging. Committee on Hearing, Bioacoustics, and Biomechanics, Commission on Behavioral and Social Sciences and Education, National Research Council" 1988); (Dubno et al. 2002); Helfer et al. (2008) According to CHABA age has been found to be a determining factor in the ability to understand speech. This age effect can be related to age-dependent alterations in one or several of three processing domains: peripheral, central, and cognitive. The peripheral domain, in particular the performance of the inner ear is motivation in the present work. Our study covered a selection of measures of hearing acuity, temporal processing, frequency selectivity and a speech recognition task in noise to get a broad profile of performances between young and elderly listeners. For a realistic and external valid impression of hearing performance of young and elderly participants in the present study both groups were not matched. We knew about the supposed weakness in the design, as we dipped into the discussion of peripheral age-related factors. Our study focused on supra-threshold auditory functions in young and elderly listeners without self-reported hearing loss referring to worse speech identification performance in elderly and less ganglion cells in aging inner ears.

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Differences in Supra-Threshold Auditory Function in young and elderly normal hearing Adults.

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Schlüsselwörter: Supra Threshold Measures, Frequency Selectivity, Temporal Compression, Aging

Introduction

Prior studies investigated why older adults, even in the absence of hearing impairment, typically experience increased difficulties understanding speech in noise. ("Speech understanding and aging. Working Group on Speech Understanding and Aging. Committee on Hearing, Bioacoustics, and Biomechanics, Commission on Behavioral and Social Sciences and Education, National Research Council" 1988); (Dubno et al. 2002); Helfer et al. (2008) According to CHABA age has been found to be a determining factor in the ability to understand speech. This age effect can be related to age-dependent alterations in one or several of three processing domains: peripheral, central, and cognitive. The peripheral domain, in particular the performance of the inner ear is motivation in the present work.

Our study covered a selection of measures of hearing acuity, temporal processing, frequency selectivity and a speech recognition task in noise to get a broad profile of performances between young and elderly listeners. For a realistic and external valid impression of hearing performance of young and elderly participants in the present study both groups were not matched. We knew about the supposed weakness in the design, as we dipped into the discussion of peripheral age-related factors.

Our study focused on supra-threshold auditory functions in young and elderly listeners without self-reported hearing loss referring to worse speech identification performance in elderly and less ganglion cells in aging inner ears.

Material and Method

Participants

The study included two groups of participants, the younger adults consisting 17 participants (21-31 years, $M_{Age} = 26$ years, $SD = 3$ years) and the older adults consisting 22 participants (68-84 years, $M_{Age} = 73$ years, $SD = 5$ years).

Hearing acuity (pure-tone air conduction) was tested from 500 Hz to 4000 Hz. The participants were required to have averaged pure-tone air conduction audiometric thresholds of 30 dB HL or less at frequencies from 500 Hz to 4000 Hz symmetrically in both the ears.

According to the Hearing Impairment grading scale of the World Health Organization (WHO, 2006) a PTA of 25 or less (frequencies 500, 1000, 2000 and 4000 Hz) would be graded as 0 (no impairment) and a PTA between 26 and 40 dB as 1 (slight impairment). All the participants were fluent Swiss German or German speakers. The participants received monetary compensation or course credits and provided informed consent before testing. The study was conducted in accordance with the human ethics standards and received approval from the research ethics board of the Psychological Institute of University of Zurich.

Procedure and stimuli Supra-Threshold Measures

The user interface based on MATLAB Auditory Periphery (MAP) model (Lecluyse, 2013; Meddis, 2013) was used for the following measurements. Procedure and stimuli were executed as described in Lecluyse, 2013 and presented monaurally.

Absolute thresholds

Absolute thresholds were measured using a simple probe-detection task. These thresholds were assessed using 250-ms pure tones at frequencies (f) 0.5, 1, 2 and 4 kHz. Next, absolute thresholds for 16-ms tones were measured at the same frequencies and these thresholds were used as the basis for the probe-tone levels in the following forward masking tasks.

Frequency selectivity

Frequency selectivity was assessed using a forward-masking task, consisting of a 108-ms masking tone followed by a 16-ms probe tone presented at ≥ 10 dB above its own (16-ms) threshold, with a masker-probe gap of 10 ms. Patients, especially elderly patients reported in some cases that the presented probe tone was not audible from the beginning of the adaptive measurement. For reasonable threshold-measurements in all cases, the level was increased in 5 dB increments until audibility was reached. This fact differs from the procedure as described in Lecluyse, 2013.

A forward-masking task identifies the quietest masking tone which is still capable for hearing the probe tone. Listeners were reporting whether or not they heard the probe tone during the measurement. The masker level was varied adaptively between trials to identify the masked threshold.

Between threshold measurements, the masker frequency varied relatively to the probe frequency to generate an iso-forward masking contour (IFMC).

Masked thresholds were measured at five different masker frequencies (f_m) specified relatively to the probe frequency (f_t), where (f_m) 0.7, 0.9, 1, 1.1 and 1.3 (f_t) (based on Lopez-Poveda et al, 2003). Masker frequencies were presented in random order between trials and IFMCs were measured for the probe frequencies 0.5, 1, 2 and 4 kHz.

Compression

With a forward-masking task using a 108-ms masking tone followed by a 16-ms probe tone presented at 10 dB above its threshold compression was measured. The gap between the masker and the probe varied between measurements while the masker frequency was constant.

Gaps used were 10, 30, 50 and 70 ms. Masker-probe gaps were presented in random order between runs. The four resulting masked thresholds produced a temporal masking curve (TMC).

The steepness of the slope is interpreted as the amount of compression because the masker will result in larger increases in the masker level as the gap increases between masker and probe. TMCs were determined for a range of *probe* frequencies, in the present study at 0.5, 1, 2 and 4 kHz.

The task was made as user-friendly as possible by the *use of cues*. All stimuli (probe alone or masker-probe tone combinations) were preceded by cue stimuli. These were identical to the test stimuli in all respects except for a single difference arranged so that the cue tone/probe was always more audible in the cue stimulus compared to the test tone/probe in the test stimulus.

Procedure and stimuli Speech Reception Threshold (SRT)

The SRT was measured using the OLSA Matrix Test. The adaptive procedure follows Wagener et al. (1999, 2003). Test stimuli and competing background noise for speech recognition were presented from the same speaker positioned at 0° azimuth, 1.5 m away from the subject's head when seated at 65 dB SPL.

The intensity level of each sentence was adaptively adjusted following each response, to obtain SRT, *i.e.*, the signal-to-noise ratio at which a 50% correct speech understanding score was achieved. The competing noise was generated by 30 random overlays of the whole test material, resulting in a signal with low amplitude modulations having the same long term spectrum as the test sentences, thereby leading to a high accuracy and reproducibility and very steep discrimination functions for speech intelligibility in noise of about 17%/dB for normal hearing listeners.

Results

Effects of Age on Absolute Thresholds

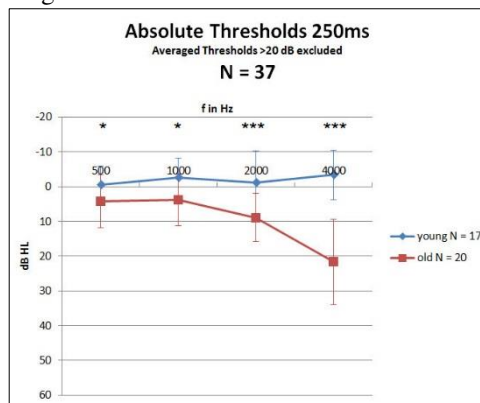


Fig.1. Averaged **250 ms** pure-tone thresholds (in dB HL) of both listener groups

Averaged audiograms of both listener groups are shown in Fig.1. Descriptive statistics confirmed that both groups had near normal hearing, defined as averaged pure-tone thresholds for 250ms-tones ≤ 30 dB HL up to 4 kHz in both ears. Surprisingly, only four participants achieved averaged pure-tone thresholds for 250ms-tones ≥ 20 dB HL in one or in both ears. For reasons to reduce existing variance between young and elderly participants the results from these participants were excluded from further analysis.

Audiometric thresholds for 250ms-tones in dB HL - averaged for both ears per frequency for both age groups show higher means at higher standard deviations in all frequencies for the elderly participants. In summary the elderly show poorer absolute thresholds for 250ms-tones in comparison to the younger participants.

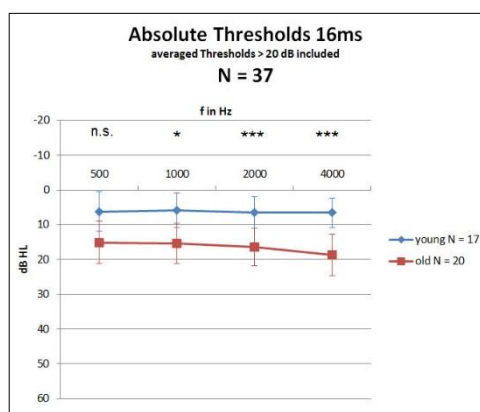


Fig.2. Averaged **16 ms** pure-tone thresholds (in dB HL) of both listener groups

Averaged hearing thresholds for 16ms tones of both listener groups are shown in Fig.2.

As expected are the absolute thresholds for 16ms between 4 and 10 dB higher than the 250ms-thresholds in both groups. The audiometric thresholds for 16ms-tones in dB HL - averaged for both ears per frequency for both age groups show again higher means at slightly higher standard deviations in all frequencies for the elderly participants. So, the elderly show also poorer absolute thresholds for 16ms-tones in comparison to the younger participants.

Effect of Age on Frequency Selectivity

For descriptive analysis we normalized the IFMC-results at the center frequency.

The obvious differences between young and elderly example-IFMC lead us to the expectation of considerably differences in the measured data. At first view (without included standard deviations) there are differences between both averaged samples. At second view (with included standard deviations) the differences will disappear or occur charily in IFMC at 4000 Hz.

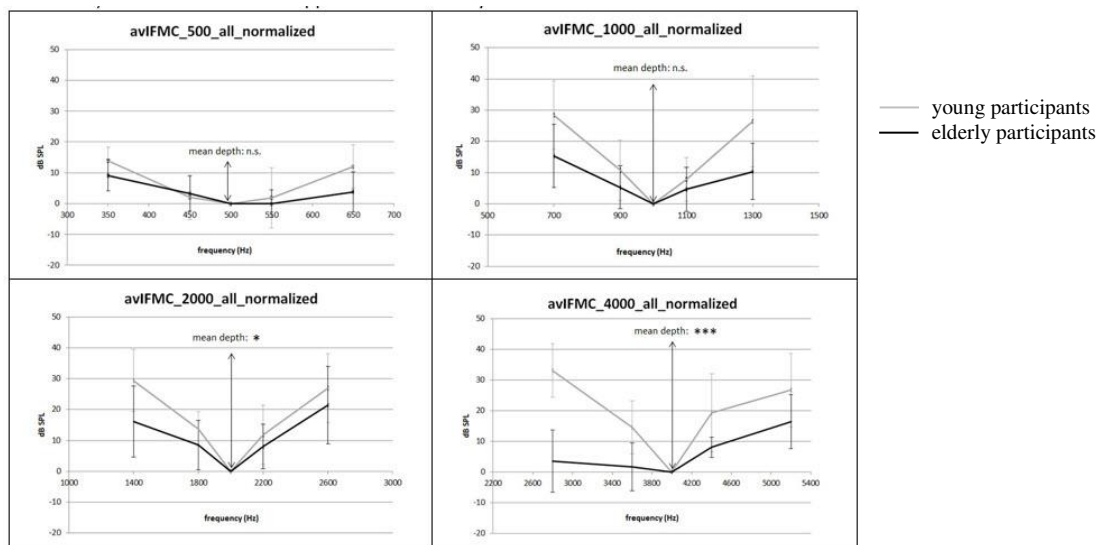


Fig.3. Normalized IFMC-results for young and elderly participants

Based on Lecluyse's et al. work we analyzed the mean depth of all IFMC-measurements.

Most of the samples were normal distributed (Shapiro Wilk, $P > 0.05$), except the mean depth of the young participants at 500 and 4000 Hz (Shapiro Wilk, $P < 0.05$). Levene-Test for homogeneity of variances showed homogeneity in the variances of the samples $P_{\text{mean_depth_500}} = 0.220 (> 0.05)$ homogenous; $P_{\text{mean_depth_1000}} = 0.597 (> 0.05)$ homogenous; $P_{\text{mean_depth_2000}} = 0.419 (> 0.05)$ homogenous; $P_{\text{abs_Thr_4000}} = 0.025 (< 0.05)$ not homogenous. For these reasons statistical analysis was continued with T-Test for 2 independent samples for the mean depth of 2000 Hz ($P = 0.005$), which result in a significant difference. For 500 ($P = 0.331$), 1000 ($P = 0.114$) and 4000 Hz ($P = 0.000$)-mean depths are no significant differences between 500 and 1000 Hz samples using the non-parametric Mann Whitney U-test. For the mean depth of 4000 Hz this test showed a high significant difference between the mean depths of the IFMC's of younger and older participants.

We observed – especially in the elderly population – very flat IFM-curves with sometimes unusual trends if a V-shape is expected. As seen in the examples it could be also interesting in analyzing the bandwidth of the V-shaped IFM – results in addition to the depth of the IFMC's. Based on Glasberg/Moore's (1990) work we fitted functions to our results in a linear and in an exponential way for calculating the Q-factor as a quality-factor for bandwidth of an auditory filter. However, these analyses did not provide significant information about differences in the IFM-results of both samples.

Effect of Age on Compression

Again we observed – especially in the elderly population – very shallow TMC-slopes with sometimes unusual trends as expected. For the measured frequencies 500, 1000, 2000 Hz the TMC-slopes are very similar between young and elderly participants. Differences disappear in large variations. The TMC-slopes for 4000 Hz show significant differences between both samples.

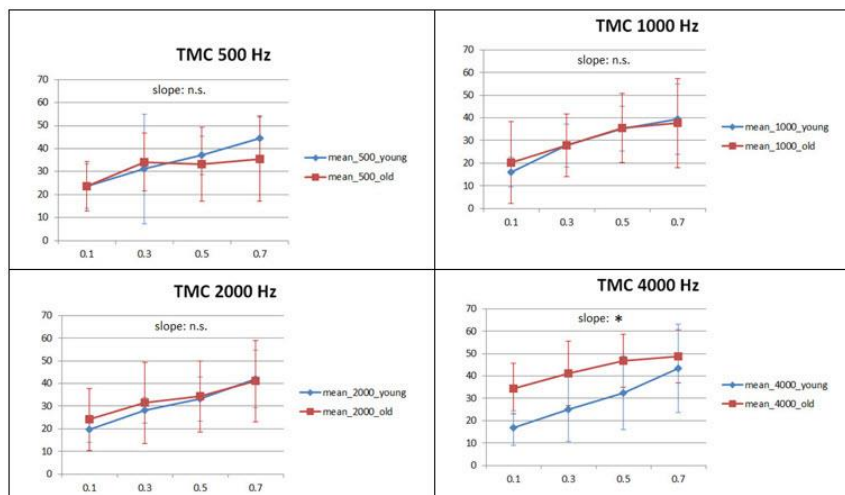


Fig.4: TMC-results for young and elderly participants

Most of the slope samples were normal distributed (Shapiro Wilk, $P > 0.05$), except the sample for 500 Hz for young participants. Levene-Test for homogeneity of variances showed no significant results in the samples $P_{TMC_{500}} = 0.318$ (> 0.05) homogenous; $P_{TMC_{2000}} = 0.522$ (> 0.05) homogenous; $P_{TMC_{4000}} = 0.076$ (> 0.05) homogenous and one significant result $P_{TMC_{1000}} = 0.007$ (< 0.05) not homogenous.

For these reasons statistical analysis was continued with T-Test for 2 independent samples for the TMC's 500 Hz ($P = 0.229$), 2000 Hz ($P = 0.522$), 4000 Hz ($P = 0.036$), which results in not significant differences for the TMC's of 500 and 2000 Hz, but showed a significant difference for the TMC of 4000 Hz. For the TMC of 1000 Hz ($P = 0.377$) there is a no significant difference between both samples – analyzed with the nonparametric Mann-Whitney U-Test for 2 independent samples.

Effect of Age on Speech Reception Threshold

The means speech reception threshold (SRT) as determined using the OLSA ($N_{\text{young}} = 17$; $N_{\text{old}} = 20$) were **-5.5 dB** for the young (min -4.7 dB; max -6.7 dB) and **-3.4 dB** for the elderly participants (min -1.6 dB; max -4.7 dB).

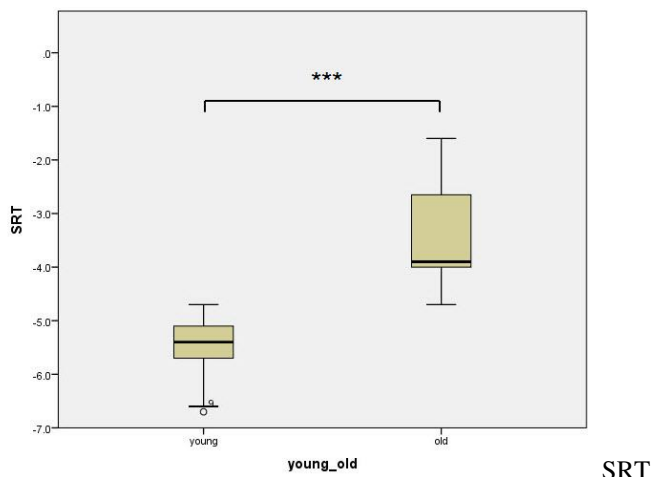


Fig.5: SRT-results for young and elderly participants

Median values of the Oldenburger Sentence Test (OLSA) used to determine the Signal-to-Noise ratio at which 50% of the presented sentences were understood correctly in noise

There was a significant correlation between the OLSA results of both age groups ($r^2 = 0.733$; $p < 0.01$).

Conclusion

Compared to the published auditory profiles from Meddis (2013) the profiles of the younger participants in our study correspond to the profiles which represent good hearing. In contrast the profiles of our elderly participants correspond partially to Meddis profiles of fewer inner hair cells (IHC) and auditory nerve (AN) synapses (reduced to 40% of original density) and to profiles with reduced outer hair cells (OHC) function or a combination of both profiles. The profiles indicate that age-related peripheral changes in the inner ear are possible and measurable, although the absolute auditory thresholds are in the range of normal hearing by definition.

Moore (psychology of hearing) describes the broadening of the auditory filter as a characteristic of hearing impairment with occurrence of perceptual deficits which are not corrected by a conventional hearing aid. Furthermore, Moore points out that the critical bandwidth (CB) should not be regarded as a complete specification of the filter, but merely as a rough indication of its bandwidth. Broad auditory filter – measured with a forward masking paradigm - like in the present study may tell us more about an ageing process in absence of hearing impairment by definition. Here we accentuate the fact that our auditory periphery measurements (exempt from threshold measurements) were executed **above** threshold where we ensured audibility and where we expected equal or similar auditory profiles by definition for the younger and the elderly participants. However, we could show differences in frequency selectivity and temporal resolution abilities between young and elderly participants. The multivariate analysis supports this idea and identified the averaged mean depth as a variable and meaningful latent factor for age.

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